Science of the Total Environment 643 (2018) 1590–1601

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Renewable energy, nuclear energy, and environmental pollution: Accounting for political institutional quality in South Africa

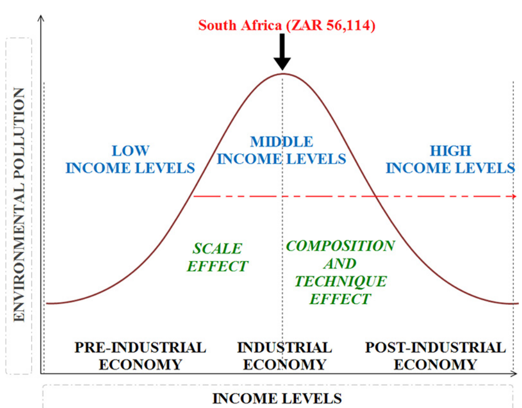
Samuel Asumadu Sarkodie [a,*], Samuel Adams [b]

[a] Faculty of Science and Engineering, Department of Environmental Sciences, Macquarie University, NSW 2109, Australia
[b] Ghana Institute of Management and Public Administration, GIMPA School of Public Service and Governance, P.O. Box AH 50, Accra North, Ghana

HIGHLIGHTS

- The EKC hypothesis is valid in South Africa at a turning point of ZAR 56,114.
- 1% increase in fossil fuel will increase CO_2 emissions by 10,436 kt in the long term.
- 1% increase in renewable energy decreases CO_2 emissions by 2865 kt in the long-run.
- Aggregate energy consumption and economic growth intensify environmental pollution.
- Political institutional quality declines environmental pollution by 0.1% in the long-run.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 May 2018
Received in revised form 19 June 2018
Accepted 26 June 2018
Available online 4 July 2018

Editor: D. Barcelo

JEL classifications:
Q43
C33
O13

Keywords:
Renewable energy
Disaggregate energy
Nuclear energy
Climate change
South Africa

ABSTRACT

This study examined the impact of disaggregate and aggregate energy, economic development, urbanization and political institutional quality on environmental pollution using a time series data spanning from 1971 to 2017. The study employed response surface regressions, structural break cumulative sum (CUSUM) test based on recursive residuals and ordinary least squares (OLS) residuals for parameter stability en route to estimating the autoregressive distributed lag (ARDL) regression. The environmental Kuznets curve (EKC) hypothesis is valid in South Africa with an extreme point of ZAR 56,114 which occurred in 2011. Evidence from the study reveals that political institutional quality plays a huge role in the social, governance and economic readiness to mitigate climate change and its impact. Structural adjustment in disaggregate and aggregate energy consumption, economic growth, and political institutional quality play a critical role in environmental quality. Fossil-fuel rich countries require diversification of the energy portfolio by incorporating renewable energy sources which will promote environmental sustainability and improve air quality while reducing their economy's vulnerability to price volatility. A paradigm shift from energy and carbon-intensive industries to a service-oriented economy will cause a structural economic change thus, aiding in the mitigation of climate change and its impacts.

1. Introduction

Modernization with its associated changing lifestyles and the need for reliable modern energy access is expected to require energy supply

* Corresponding author.
E-mail address: asumadusarkodiesamuel@yahoo.com (S.A. Sarkodie).

https://doi.org/10.1016/j.scitotenv.2018.06.320
0048-9697/

to be at least doubled from 2016 to 2030. The situation is worsened by energy-sector bottlenecks and power shortages which cost the African region 2–4% of GDP annually, which undermines growth, jobs, and investment. The Africa Progress Panel (APP) (2016) estimates that some 600 million people on the continent do not have access to electricity, a figure that will require $55bn per year in investment by 2030 to fix. It is not surprising that more than 2.7 billion people – 38% of the world's population – are estimated to rely on the traditional use of solid biomass for cooking mostly in Asia and Sub-Sahara Africa (WEO, 2016). Renewable energy and the application of nuclear energy technology have acquired a reputation among policymakers as cost-effective and environmentally friendly sources of energy.

To mitigate the continuous problem of sustainable energy supply, the South African government has committed itself to pursue renewable energies (RE) vigorously as a viable alternative to traditional sources such as fossil fuels. It was in 2003 that renewable energy became prominent in South African policy document, where it outlined the strategic intention for RE for the next decade (Weideman et al., 2017). In the light of this, the South African government formed the Renewable Energy Independent Power Producers Procurement Programme (the REI4P), an extensive initiative infrastructure to install 17.8 GW of electricity generation capacity from renewables – wind, solar, biomass, biogas and hydropower to reduce carbon emissions over the period 2012–2030 (Walwyn and Brent, 2015).

South Africa is the seventh largest exporter of coal and among the top emitters of fossil fuel related emissions, as nearly 90% of its energy (42.8 GW) is produced from coal (Baker, 2017; Nakumuryango and Inglesi-Lotz, 2016). Appreciating the contribution of coal-generated energy to the rising issues of global climate change, the South African government recognized the need to achieve a sustainable energy mix by developing renewable energy source. To deepen this resolve, it developed an integrated Resource plan in 2010 to promote RE and more recently, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in 2014. The result of these initiatives and particularly the grid-connected RE auctions have seen grid prices fall, as one of the lowest in the world with solar PV prices as low as USc 6.4/kWh and the cheapest wind at USc 4.7/kWh (Eberhard and Kåberger, 2016). It is noteworthy that South Africa's renewable energy industry has faced challenges including resistance by the electricity utility Eskom (State monopoly), which is embroiled with scandals of state capture and corruption, as well as the ability of Eskom's transmission grid to integrate renewable energy generation (Baker, 2017).

Additionally, with climate change being regarded as one of the most pressing global problems, nuclear energy has found its way into policy roundtables all over the world (Lenzen, 2008). The World Nuclear Performance Report (2017) indicates that over 9GWe nuclear capacity came online in 2016, which is the largest increase in the last quarter of a century. The amount of electricity supplied by nuclear power globally increased from 35 TWh to 2476 TWh, and there are plans to increase electricity supply by nuclear energy to 25% of the world's electricity by 2050. Currently, the only nuclear power plant operational in sub-Saharan Africa is in South Africa which accounts for 5% of the electricity generating capacity. Government has a strong commitment to the future of nuclear energy, with firm plans for further 1300 MWe in the face of significant financial constraints (World Nuclear Association, 2017).

With the impetus for renewables, the big question is how has this impacted on the environment? This is the question the study seeks to answer. It is important to mention that to date; many studies have examined the effect of renewable and nuclear energy on economic growth but not much on how they impact carbon emissions. Thus, the study fills this is gap, because the few available literature have yielded mixed results (Apergis et al., 2010; Saidi and Mbarek, 2016). This suggests that country-specific studies could help shed more light on the scope of the study.

To achieve the research objective and provide consistent estimates, the study further considers two other variables (urbanization and political institutional quality), which the literature suggests have an impact on the environment. However, there are no empirical studies to examine the importance of the indicators to provide evidence for policy formulation. Accordingly, to reduce the problem of omitted variable bias, we control for the urbanization process. The study examines how institutional environment moderates the energy-environment degradation link. In achieving the research objective, we contribute to the literature in three main ways. First, we do a comparative analysis of the effect of nuclear energy, renewable and non-renewable energy on carbon emissions. Second, we examine the independent and moderating role urbanization on the energy-environmental pollution association. Third, the political economy of the energy-environmental pollution link is investigated. Finally, we employ a more robust technique; ARDL bounds testing procedure by using critical values and approximate p-values based on response surface regression and CUSUM test for detecting structural breaks over the period 1971–2017.

The rest of the paper is organized as follows: Literature review, Methodology, Results and discussion, and Conclusion.

2. Literature review

The literature on the energy – environmental degradation link is vast with no consistent results. There are two strands of the energy – environmental degradation literature; the first focuses on the overall energy and the second, examines the differential effects of the components (renewable versus nonrenewable). For example, Dogan and Seker (2016a) examine the energy consumption, urbanization and carbon dioxide emissions link for the USA over the period 1960–2010 and show that in the long run, energy consumption and urbanization increase environmental degradation. Similarly, Franco et al. (2017) in a study of India over 110 years (1901–2011) find that urbanization improves the quality of life of people while promoting economic growth; however, it also increases energy consumption and has a significant impact on carbon dioxide emissions. Martínez-Zarzoso and Maruotti (2011) show that the effect of urbanization is moderated by the level of development. The authors find that urbanization demonstrates a very different impact on emissions for low, lower-middle-income and upper-middle income countries. Liddle (2014) in a review of macro-level studies on urbanization and population dynamics find that urban density has a negative effect on carbon emissions.

Decomposing the energy variable into renewable and nonrenewable energy, Shafiei and Salim (2014), Dogan and Seker (2016a), Dogan and Seker (2016b) and Jebli et al. (2016) find that non-renewable energy consumption raises CO_2 emissions while renewable energy consumption reduces CO_2 emissions in OECD countries. Al-Mulali et al. (2015) find that non-renewable energy consumption enhances CO_2 emissions, while renewable energy consumption has no effects on CO_2 emissions in Vietnam. In another study of Kenya over the period 1980–2012 based on ARDL, Al-Mulali et al. (2016) report that renewable energy reduces CO_2 emissions while non-renewable energy, and urbanization increase environmental pollution. In a regional study of 25 SSA, Zoundi (2017) shows a negative effect of renewable energy on carbon emissions. Nonetheless, the impact of renewable energy is outweighed by primary energy consumption in both the short and long run. Investigating the relationship for developing countries based on panel econometric analysis of annual data from 1990 to 2012, Paramati et al. (2017) show that renewable energy consumption positively contributes to economic output and environmental quality. Accordingly, the authors recommend that policymakers initiate effective policies to promote more renewable energy generation. Controlling for cross-sectional dependence, using the cross-sectionally augmented Dickey Fuller (CADF) and cross-sectional augmented Im, Pesaran and Shin (CIPS) tests, Irfan and Shaw (2017) find that renewable energy decreases carbon emissions, while nonrenewable energy increase emissions in the EKC

model for the top countries listed in the Renewable Energy Country Attractiveness Index.

Some studies provide results contrary to those discussed above. For example, Apergis et al. (2010) examine the causal relationship between CO_2 emissions, nuclear energy consumption, renewable energy consumption, and economic growth for a group of 19 developed and developing countries for the period 1984–2007 using a panel error correction model. The long-run estimates indicate that there is a statistically significant negative association between nuclear energy consumption and emissions, but a statistically significant positive relationship between emissions and renewable energy consumption. The authors conclude that renewable energy does not contribute to the reduction of carbon emissions. This may be due to the lack of adequate storage technology to overcome intermittent supply problems as a result, electricity producers must rely on emission generating energy sources to meet peak load demand. This is also in line with the findings of Menyah and Wolde-Rufael (2010) for the US that renewable energy did not contribute to carbon emissions reduction.

Additionally, some studies do not show differential effects between renewable and nonrenewable energy on carbon emissions. Farhani and Shahbaz (2014) analyze the case for Middle East and North Africa (MENA) countries by applying the fully modified ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS) on data from 1980 to 2009 and conclude that both renewable and non-renewable energy increases the level of emissions. Mert and Bölük (2016) investigate the case of 16 European Union (EU) countries over the 1990–2008 period using OLS and fixed effects and find that both renewable and nonrenewable energy consumption contributes to environmental degradation though renewable energy contributes around 1/2 less per unit of energy in terms of GHG (greenhouse gas) emissions. In a related study of the MENA region from 1980 to 2009, based on Breitung IPS and Pedroni cointegration techniques, Bilgili et al. (2016) demonstrate that both renewable and nonrenewable energy contribute to carbon dioxide emissions.

Some other studies, however, report that renewable energy has a positive impact on the environment only when it has reached a certain minimum threshold. According to Chiu and Chang (2009), renewable energy supply must account for 8.39% of total energy supply before any impact on mitigating CO_2 emissions could be observed. Indeed, the results show that below the threshold, renewable energy contributes to environmental degradation. Heal (2009) and Forsberg (2009) claim that renewable energy may not reduce emissions because of the intermittent nature of its output and the lack of adequate storage technology for renewable energy. Threshold effects have also been reported for urbanization. For example, Irfan and Shaw (2017) examined three Asian countries (India, Pakistan, and Bangladesh) over the period 1978–2011 using fixed effects to show support for the Kuznets curve. More importantly, the results suggest that there exists a threshold below which increases in urbanization increases carbon emissions but after the threshold is reached, further urbanization leads to a fall in carbon dioxide emissions.

Bhattacharya et al. (2017) extend the literature by discussing the role of institutions (economic freedom) in the energy consumption and environment relationship using various econometric tools including GMM and FMOLS for 85 developed and developing countries over the period 1991–2012. The results of the study show that both renewable energy and institutions have a positive influence on growth and environmental quality. Al-Mulali et al. (2015) used FMOLS to show that energy consumption, urbanization, trade openness and industrial development increase environmental damage while political stability lessens it in the long run for MENA countries over the period 1996–2012. Adams et al. (2016a, 2016b) report that both the regime type and regime stability matter in explaining environmental outcomes. Similarly, Adams and Klobodu (2017) argue that though democracy matters, democratic consolidation is more important in explaining environmental policy outcomes. This study contributes to the debate by examining how both political and economic institutions affect the energy-carbon dioxide relationship. The methodology for achieving the objectives is discussed next.

3. Methodology

3.1. Data

To meet the objectives, the study employs time series data from the World Bank Development Indicators (World Bank, 2016), U.S. Energy Information Administration (EIA, 2017), and University of Gothenburg (UoG, 2017). The eight data series include Urban population (URB), CO_2 emissions (CO_2E), Energy use (EGUSE), Political institutional quality (PIQ), Renewable energy (RENE), Fossil Fuel energy (NRENE), GDP per capita (GDPPC) and Nuclear Electricity Net Generation (NUC), presented in Table 1. The selection of the variables is motivated by the Sustainable Development Goals by 2030.

Due to data availability, the missing data within the series were filled using the seasonal algorithm (exponential smoothing) which accounts additive error, additive trend and additive seasonality (AAA) based on a 99.99% confidence interval available in Microsoft Excel. Thus, the period of the data used for the empirical analysis spans from 1971 to 2017, using South Africa as a case study.

Fig. 1 shows the trend and the graphical representation of the data series under study. From observation, it appears that CO_2 emissions, GDP per capita and urbanization exhibit an increasing trend compared to the other data series. One may be attempted to believe that there are issues of structural breaks by just observing the pictorial view of the data series. As such, issues related to structural breaks would be discussed exhaustively in the subsequent sections of the study.

To better understand the characteristics of the data series prior to estimating the model, the study descriptively analyzes the study variables presented in Table 2. Based on the available data, the averages of the variables are quantified as: CO_2 emissions, 348,274 kt; energy use, 2450 kg of oil equivalent per capita; GDP per capita, 22,495 South African Rand (ZAR); fossil fuel energy, 87%; nuclear electricity generation, 8%; political institutional quality, 0.40 relative factor scores; renewable energy, 17%, and urbanization, 22,369,184 people.

Table 2 reveals that except CO_2E, EGUSE, NRENE, and NUC, all the remaining variables are positively skewed. However, only NUC has excess kurtosis exceeding 3 thus, exhibiting a leptokurtic distribution. The Jarque-Bera test of normal distribution reveals that all the variables are normally distributed in their raw values except for GDPPC, and PIQ.

The test of association using correlation reveals that while all the variables have a positive relationship with CO_2 emissions except for fossil fuel energy, however, in reality, sounds deceptive. Meaning that the descriptive statistics are unable to examine causation, thus, requires inferential statistics to empirically examine the causal nexus between CO_2 emissions used as a proxy for environmental pollution and the predictor variables under study.

Table 1
Variable definition.

Series name	Abbreviation
Urban population	URB
CO_2 emissions (kt)	CO_2E
Energy use (kg of oil equivalent per capita)	EGUSE
Political institutional quality (relative factor scores)	PIQ
Renewable energy (%)	RENE
Fossil Fuel energy (%)	NRENE
GDP per capita (current LCU)	GDPPC
Nuclear Electricity Net Generation (billion kWh)	NUC

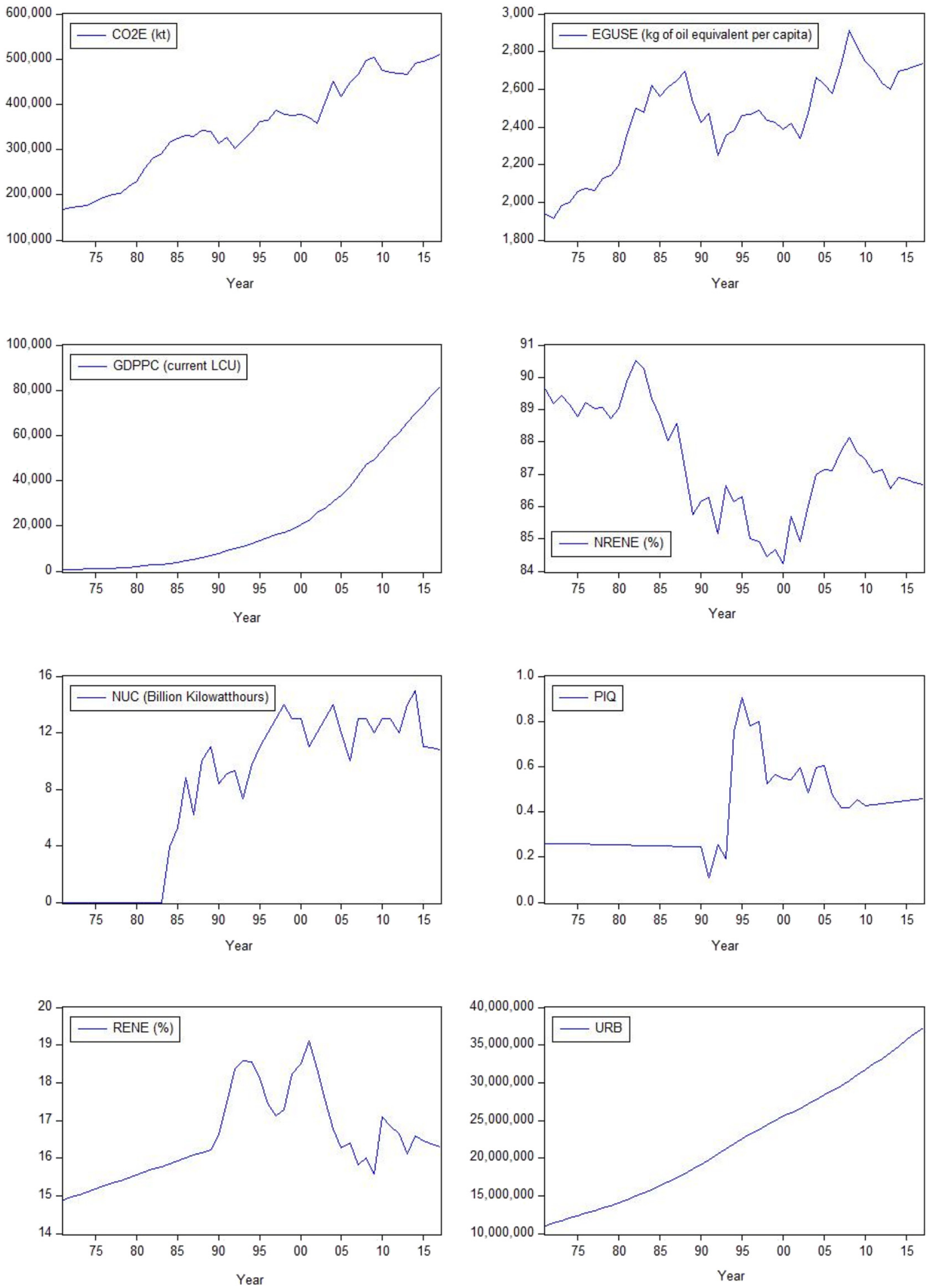


Fig. 1. The trend of data series. Legend: Urban population (URB), CO_2 emissions (CO_2E), Energy use (EGUSE), Political institutional quality (PIQ), Renewable energy (RENE), Fossil Fuel energy (NRENE), GDP per capita (GDPPC) and Nuclear Electricity Net Generation (NUC).

3.2. Model estimation

The study employs three relationship models with ARDL specification following the work of Asumadu-Sarkodie and Owusu (2016) expressed as a linear function below:

$$CO_2E_t = f\left(LRENE_t, LNRENE_t, LGDPPC_t, LGDPPC^2{}_t, LPIQ_t\right) \quad (1)$$

$$CO_2E_t = f\left(LRENE_t, LNRENE_t, LNUC_t, LGDPPC_t, LGDPPC^2{}_t, LPIQ_t\right) \quad (2)$$

$$LCO_2E_t = f(LEGUSE_t, LURB_t, LGDPPC_t, LPIQ_t) \quad (3)$$

Model 1–2 in Eqs. (1)–(2) is based on a level-log regression using the EKC hypothesis pathway contrary to Model 3. Moreover, Model 1–2 represents the disaggregation energy consumption while Model 3

Table 2
Descriptive statistical analysis.

Statistic	CO_2E	EGUSE	GDPPC	NRENE	NUC	PIQ	RENE	URB
Mean	348,273.7	2449.502	22,495	87.3676	7.9733	0.3960	16.5117	22,369,184
Median	343,055.2	2471.021	12,038.97	87.1497	10.0000	0.4180	16.2683	21,903,210
Maximum	509,548.4	2913.13	81,693.47	90.5063	15.0000	0.9028	19.1214	37,338,489
Minimum	168,568.3	1912.971	619.304	84.2434	0.0000	0.1066	14.8817	11,060,997
Std. dev.	105,814.8	253.4518	24,531.69	1.6717	5.4451	0.1805	1.1277	7,948,592
Skewness	−0.170204	−0.527874	1.052538	−0.0309	−0.5648	0.9135	0.6344	0.245333
Kurtosis	1.967159	2.417412	2.806119	2.0339	1.6731	3.2470	2.4141	1.816373
Jarque-Bera	2.316001	2.847446	8.751666	1.8353	5.9471	6.6559	3.8253	3.215047
Probability	0.314114	0.240816	0.012578[a]	0.3995	0.0511	0.0359[a]	0.1477	0.200383
Correlation[**]	CO_2E	EGUSE	GDPPC	NRENE	NUC	PIQ	RENE	URB
CO_2E	1							
EGUSE	0.9037	1						
GDPPC	0.8726	0.6765	1					
NRENE	−0.5181	−0.3005	−0.3299	1				
NUC	0.8780	0.7341	0.6665	−0.8106	1			
PIQ	0.5055	0.3034	0.3661	−0.6147	0.6308	1		
RENE	0.3949	0.2435	0.1645	−0.8196	0.6353	0.5522	1	
URB	0.9593	0.7626	0.9465	−0.5578	0.8488	0.5349	0.4189	1

[a] Rejection of the null hypothesis of normal distribution.
[**] Denotes 5% significance level.

represents the aggregated energy consumption. The adoption of disaggregate and aggregate energy consumption is in line with Sarkodie and Strezov (2018), they argue that the former presents valuable results in terms of interpretation. The empirical specification of Model 1–3 based on the autoregressive distributed lag (ARDL) regression is quantified as:

$$\begin{aligned}\Delta CO_{2t} = {} & \alpha_0 + \delta_1 CO_{2t-1} + \delta_2 LRENE_{t-1} + \delta_3 LNRENE_{t-1} \\ & + \delta_4 LGDPPC_{t-1} + \delta_5 LGDPPC^2{}_{t-1} + \delta_5 LPIQ_{t-1} \\ & + \sum_{i=1}^{p} \beta_{1j} \Delta CO_{2t-i} + \sum_{i=0}^{p} \beta_{2j} \Delta LRENE_{t-i} \\ & + \sum_{i=0}^{p} \beta_{3j} \Delta LNRENE_{t-i} + \sum_{i=0}^{p} \beta_{4j} \Delta LGDPPC_{t-i} \\ & + \sum_{i=0}^{p} \beta_{5j} \Delta LGDPPC^2{}_{t-i} + \sum_{i=0}^{p} \beta_{6j} \Delta LPIQ_{t-i} + \varepsilon_t \end{aligned} \tag{4}$$

$$\begin{aligned}\Delta CO_{2t} = {} & \alpha_0 + \delta_1 CO_{2t-1} + \delta_2 LRENE_{t-1} + \delta_3 LNRENE_{t-1} + \delta_4 LNUC_{t-1} \\ & + \delta_5 LGDPPC_{t-1} + \delta_6 LGDPPC^2{}_{t-1} + \delta_7 LPIQ_{t-1} \\ & + \sum_{i=1}^{p} \beta_{1j} \Delta CO_{2t-i} + \sum_{i=0}^{p} \beta_{2j} \Delta LRENE_{t-i} \\ & + \sum_{i=0}^{p} \beta_{3j} \Delta LNRENE_{t-i} + \sum_{i=0}^{p} \beta_{4j} \Delta LNUC_{t-i} \\ & + \sum_{i=0}^{p} \beta_{5j} \Delta LGDPPC_{t-i} + \sum_{i=0}^{p} \beta_{6j} \Delta LGDPPC^2{}_{t-i} \\ & + \sum_{i=0}^{p} \beta_{7j} \Delta LPIQ_{t-i} + \varepsilon_t \end{aligned} \tag{5}$$

$$\begin{aligned}\Delta LCO_{2t} = {} & \alpha_0 + \delta_1 LCO_{2t-1} + \delta_2 LEGUSE_{t-1} + \delta_3 LURB_{t-1} \\ & + \delta_4 LGDPPC_{t-1} + \delta_5 LPIQ_{t-1} + \sum_{i=1}^{p} \beta_{1j} \Delta LCO_{2t-i} \\ & + \sum_{i=0}^{p} \beta_{2j} \Delta LEGUSE_{t-i} + \sum_{i=0}^{p} \beta_{3j} \Delta LURB_{t-i} \\ & + \sum_{i=0}^{p} \beta_{4j} \Delta LGDPPC_{t-i} + \sum_{i=0}^{p} \beta_{5j} \Delta LPIQ_{t-i} + \varepsilon_t \end{aligned} \tag{6}$$

where LCO_2, $LEGUSE$, $LRENE$, $LNRENE$, $LNUC$, $LGDPPC$, $LURB$, and $LPIQ$ denote the logarithmic transformation of CO_2 emissions, Energy use, Renewable energy, Fossil Fuel energy, Nuclear Electricity Net Generation, GDP per capita and Political institutional quality, the intercept is denoted by α, p is the lag order, Δ is the first difference operator, and the error term is represented as ε at time t. The ARDL regression model is used to estimate and test the level relationship between the response variable and the regressors. Importantly, ARDL model is suitable for small sample size and multiple predictors can have different lag orders.

The study employs Pesaran et al. (2001) bounds test for levels relationship where the approximate p-value and critical values for the F-tests and t-statistics are derived from Kripfganz and Schneider (2018) response surface regressions. The Null hypothesis of no co-integration between response and regressors is rejected if the approximate p-value and critical values for the F-tests and t-statistics are above the upper bound critical values.

The study analyzes the parameter stability of the time series regression by examining the existence of structural break over a period of time, in order to prevent spurious regression. We employ the cumulative sum tests namely; CUSUM test based on recursive residuals and OLS residuals for parameter stability expressed mathematically as (Brown et al., 1975):

$$C_t{}^{rec} = \frac{1}{\hat{\sigma}} \sum_{j=k+1}^{j=t} e_j{}^{rec} \tag{7}$$

where $C_t{}^{rec}$ denotes the limiting distribution of the sequence, k represents variables, t denotes time, $e_t{}^{rec}$ represents recursive residuals and variance $\hat{\sigma}^2 = \{1/(T-k)\} \sum_{k+1}^{T} (e_t{}^{rec} - e_t{}^{-rec})^2$.

$$C_t{}^{ols} = \frac{1}{\hat{\sigma}\sqrt{T}} \sum_{j=k+1}^{j=T} e_j{}^{ols} \tag{8}$$

where $C_t{}^{ols}$ denotes the limiting distribution of the sequence, k represents variables, t denotes time, $e_t{}^{ols}$ represents ols residuals and variance $\hat{\sigma}^2 = \{1/(T-k)\} \sum_{k+1}^{T} (e_t{}^{ols} - e_t{}^{-ols})^2$.

4. Results and discussion

4.1. Unit root

After examining the characteristics of the data series, the study employs the Phillips-Perron test to examine the presence of unit root among the data series. Contrary to the Augmented Dickey-Fuller unit root test that uses supplementary lags of the first difference data series, the Phillips-Perron (Phillips and Perron, 1988) unit root test accounts

Table 3
Phillips-Perron unit root test.

Variable	Intercept				Intercept & trend				None			
	Level	Prob	1st diff	Prob	Level	Prob	1st diff	Prob	Level	Prob	1st diff	Prob
CO_2E	−0.8185	0.8043	−6.8058	0.0000	−2.6217	0.2730	−6.7452	0.0000	2.5198	0.9966	−5.8943	0.0000
EGUSE	−1.8486	0.3530	−6.4746	0.0000	−2.2048	0.4757	−6.4953	0.0000	1.1356	0.9315	−6.2844	0.0000
GDPPC	9.0960	1.0000	−0.7592	0.8208	2.0978	1.0000	−4.4413	0.0049	11.4269	1.0000	0.1711	0.7311
NRENE	−1.6729	0.4380	−7.5025	0.0000	−1.6774	0.7453	−7.4641	0.0000	−0.7329	0.3936	−7.5249	0.0000
NUC	−1.4539	0.5477	−7.7865	0.0000	−1.5476	0.7980	−7.8404	0.0000	0.1364	0.7207	−7.7103	0.0000
PIQ	−2.1200	0.2380	−6.9745	0.0000	−2.4766	0.3377	−6.8995	0.0000	−0.6090	0.4481	−7.0423	0.0000
RENE	−1.9746	0.2966	−4.9835	0.0002	−1.7010	0.7348	−5.0843	0.0008	0.2602	0.7572	−5.0422	0.0000
URB	5.7959	1.0000	−0.7197	0.8313	−1.2951	0.8768	−1.7838	0.6960	18.8792	1.0000	1.8875	0.9845

for serial correlation by implementing Newey-West standard errors, as such produces more accurate unit root tests. Table 3 presents the results of Phillips-Perron unit root test in three different options namely; intercept, intercept and trend, and none. Table 3 reveals that the null hypothesis that the variables under investigation contain unit root at level cannot be rejected at 5% significance level in intercept, intercept and trend, and none. On the contrary, except GDPPC and URB, the null hypothesis that the variables unit root at first difference is rejected at 5% significance level in intercept, intercept and trend, and none. Meaning that the variables are integrated of order zero [I(0)] and order one [I(1)], except GDPPC and URB.

Contrary to other econometric techniques, the proposed ARDL by Pesaran and Shin (1998) does not require all variables to be I(1) or I(0) and I(1). However, as a precondition, the dependent variable must be non-stationary and none of the data series must be I(2) in normal conditions and in the structural break. Pesaran and Shin (1998) revealed that the ARDL bounds cointegration among the data series can have a different number of lag terms.

4.2. Structural break

In order to overcome challenges related with structural breaks in the time series variables, the study employed the cumulative sum test for parameter stability by Brown et al. (1975) to ascertain the stability of coefficients in the time series regression over time. All the two tests namely; the cumulative sum of recursive residuals and the cumulative sum of OLS residuals are analyzed in the study due to the advantage each has over the other. According to Ploberger and Krämer (1992), the cumulative sum of recursive residuals has the advantage to detect parameter instability that occurs in the early periods of the sample data. On the contrary, the cumulative sum of OLS residuals has an advantage of detecting the parameter instability for breaks in the later periods of the sample data. Thus, combining both tests is essential in the study. Another advantage of the cumulative sum test for parameter stability is that it prepares data series to be free from structural breaks prior to model estimation and produces CUSUM plots with corresponding test statistics to support the test output. Table 4 presents the results of the structural break test statistic with their corresponding plots depicted in Figs. 2–3. Figs. 2–3 show that the plotted cusum is within the 95% confidence band. Additionally, Table 4 reveals that the test statistics for all the three models using both cumulative sum test are smaller than the 1%, 5% and 10% critical values as such, cannot reject the null hypothesis that all the parameters are stable over time using the data series. Thus, the estimated models have no issues of structural break.

Table 4
Test of structural break.

Models	Statistic	Test statistic	1% critical Value	5% critical Value	10% critical Value
Model 1	ols	0.6720	1.6276	1.3581	1.2240
Model 1	recursive	0.8364	1.1430	0.9479	0.8500
Model 2	ols	0.5789	1.6276	1.3581	1.2240
Model 2	recursive	0.4495	1.1430	0.9479	0.8500
Model 3	ols	0.8459	1.6276	1.3581	1.2240
Model 3	recursive	0.6810	1.1430	0.9479	0.8500

4.3. Cointegration

The study examines the existence of a level relationship between the response and predictor variables via the famous Pesaran et al. (2001) bounds test procedure by using critical values and approximate p-values based on response surface regression from Kripfganz and Schneider (2018).

The Kripfganz and Schneider (2018) pathway to Pesaran et al. (2001) bounds test is more beneficial to estimate the upper and lower bound critical values in conditions were all long-run data series are either integrated of order zero, I(0) or order one, I(1). Moreover, the response surface estimates provide accurate finite sample critical value bounds for an unlimited number of short-run coefficients.

For brevity, the approximate p-values by Kripfganz and Schneider (2018) can be mathematically presented as:

$$F^{-1}(p) = \sum_{i=0}^{n} \varnothing_i \left\lfloor \hat{Q}(p) \right\rfloor^i + e \tag{9}$$

$$\hat{p} = F\left(\sum_{i=0}^{n} \hat{\varnothing}_i \tau^i\right) \tag{10}$$

where $F^{-1}(p)$ denotes the inverse cumulative distribution function applied under standard asymptotics, $\hat{Q}(p)$ denotes the predicted p-quantile, e denotes the error term, n denotes the higher order term, $\hat{\varnothing}_i$ denotes the estimated coefficients from Eq. (9) and $\hat{p}$ is the corresponding approximate p-value from the observed value of the test statistic τ.

Table 5 presents the ARDL bounds test for cointegration. The results in Table 5 reveals that the F-statistics and t-statistics of the three models are more extreme than the critical values for the upper bound, I(1) and corroborated by Kripfganz and Schneider (2018) approximate p-values, thus, rejecting the null hypothesis of no level relationship. In other words, the response variable and the predictor variables in the three models are cointegrated. Meaning that a more parsimonious ARDL model can be estimated following Pesaran and Shin (1998).

4.4. Long- and short-run equilibrium relationship

After rejecting the null hypothesis of no level relationship, the next step is to examine the long- and short-run equilibrium relationship between CO_2 emissions and the regressors using the ARDL model with optimal lag selection using Akaike Information Criterion of pure autoregressive processes.

Using the optimal lag in the levels regression, the estimated long- and short- run equilibrium relationship are based on ARDL(1,0,0,0,1,0) for model 1, ARDL(1,0,1,0,0,1,0) for model 2, and ARDL(1,1,1,1,1) for model 3, respectively. The long-run coefficients in Model 1 are

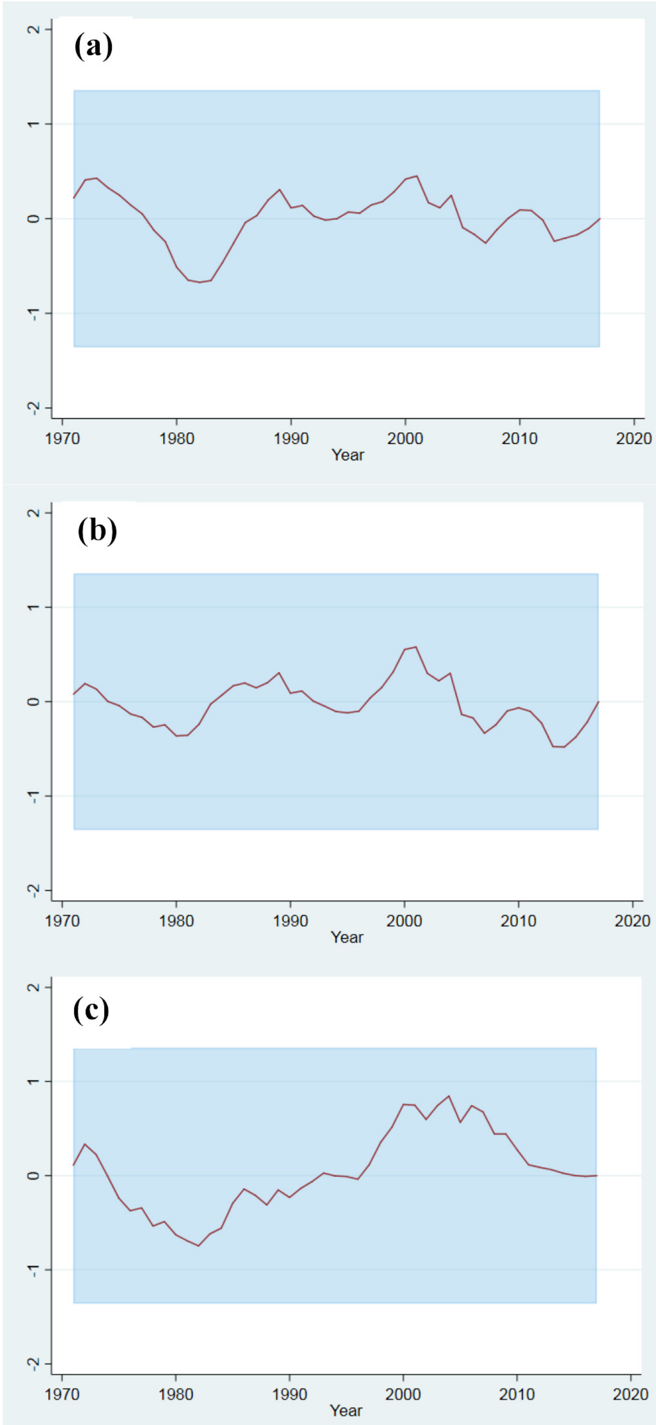


Fig. 2. Recursive CUSUM plot for structural break: (a) Model 1 (b) Model 2 and (c) Model 3.

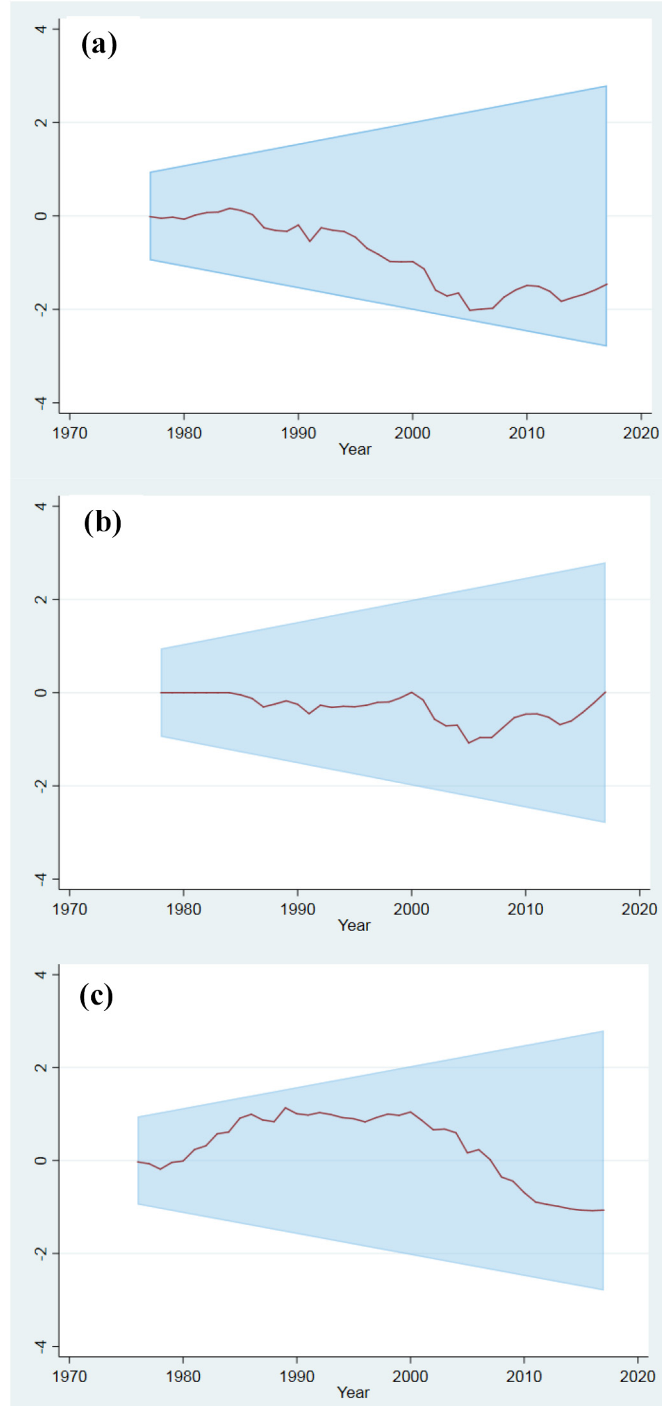


Fig. 3. OLS CUSUM Plot for structural break: (a) Model 1 (b) Model 2 and (c) Model 3.

expressed in time t (estimated in first difference form) while the long-run coefficients in Models 2 and 3 are expressed in $t-1$. Thus, reflecting in the error correction with the levels regressors. Even though both parameterizations produce identical coefficients except for the first first-difference term of each long-run independent variable.

The results of the ARDL regression for Model 1–3 are presented in Table 6. Models 1 and 2 are a level-log (i.e. $\beta/100$ in explaining coefficients) regression which shows the nexus between environmental pollution (CO_2E), disaggregate energy consumption (LRENE and LNRENE), economic growth (LGDPPC) and political institutional quality (LPIQ). The results show that disaggregate energy sources provide a detailed assessment of the effect of renewables and fossil fuel on environmental pollution.

Model 1 reveals that the error correction [$ECT(-1) = -0.65$] is negative and statistically significant at 1%. Thus, confirming a long-run relationship running from disaggregate energy consumption, economic development and political institutional quality to environmental pollution. The error correction term reveals a 65% speed of adjustment in correcting deviations from the long-run equilibrium level of environmental pollution during the first-year after short-term shocks.

Model 1 reveals that a 1% increase in the share of renewable energy declines environmental pollution by 3288 kt while a percentage increase in the share of fossil fuel in the energy mix increases

Table 5
ARDL bounds test.

Bounds	10%		5%		1%		p-Value		F/t statistic
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	
F (Model 1)	2.48	3.69	2.98	4.32	4.13	5.79	0.00	0.00	7.01
t (Model 1)	−2.56	−3.87	−2.90	−4.28	−3.60	−5.09	0.00	0.00	−5.59
F (Model 2)	2.35	3.62	2.81	4.24	3.91	5.70	0.00	0.00	8.29
t (Model 2)	−2.53	−4.01	−2.88	−4.44	−3.60	−5.31	0.00	0.00	−6.83
F (Model 3)	2.60	3.82	3.13	4.51	4.38	6.09	0.00	0.03	5.17
t (Model 3)	−2.53	−3.64	−2.88	−4.04	−3.57	−4.83	0.00	0.01	−4.82

environmental pollution by 8913 kt. The outcome is in line with Mohiuddin et al. (2016) which shows that electricity generation from oil, natural gas, and oil contributes to environmental degradation.

The sign of per capita GDP (LGDPPC) is positive while the sign of the squared per capita GDP ($LGDPPC^2$) is negative and both exhibiting statistical significance at 1%, which suggest that, in the long-run, environmental pollution will increase by 13% ($i.e. -0.5 * \frac{LGDPPC}{LGDPPC^2}$) at the initial stage of economic development and decreases thereafter with increasing economic productivity. Thus, validating the EKC hypothesis in South Africa.

The nexus between environmental pollution and political institutional quality is negative yet insignificant in Model 1.

In the business as usual scenario, the short-run equilibrium relationship in Model 1 reveals that disaggregate energy consumption, economic development, and political institutional quality will reduce environmental pollution by 27,901 kt in the short-term.

Table 6
ARDL regression with long- and short-run equilibrium relationship.

	$\Delta L/CO_2E$	Coef.	Std. err.	t	p > t
Model 1					
ADJ	ECT(−1)	−0.6457	0.1154541	−5.59	0.0000*
LR	LRENE	−328,847.9	92,462.24	−3.56	0.0010*
	LNRENE	891,285	346,892.3	2.57	0.0140**
	LGDPPC	276,410.6	53,250.63	5.19	0.0000*
	$LGDPPC^2$	−10,641.29	2823.255	−3.77	0.0010*
	LPIQ	−9641.346	9496.722	−1.02	0.3170
SR	_cons	−2,790,194	1,035,229	−2.7	0.011**
Model 2					
ADJ	ECT(−1)	−0.7819	0.1145	−6.8300	0.0000*
LR	LRENE	−286,501	75,388	−3.8000	0.0010*
	LNUC	15,970	9503	1.6800	0.1020
	LNRENE	1,043,614	314,461	3.3200	0.0020*
	LGDPPC	208,125	62,517	3.3300	0.0020*
	$LGDPPC^2$	−7447	3156	−2.3600	0.0240**
	LPIQ	−7018	7134	−0.9800	0.3320
SR	ΔLRENE	−224,006	67,909	−3.3000	0.0020*
	ΔLNUC	25,551	8438	3.0300	0.0050*
	ΔLNRENE	815,967	247,321	3.3000	0.0020*
	ΔLGDPPC	162,726	50,790	3.2000	0.0030*
	$\Delta LGDPPC^2$	−12,654	5460	−2.3200	0.0270**
	ΔLPIQ	−5487	5472	−1.0000	0.3230
	_cons	−3,741,482	1,137,020	−3.2900	0.0020*
Model 3					
ADJ	ECT(−1)	−0.7315	0.1518	−4.8200	0.0000*
LR	LEGUSE	1.2570	0.1256	10.0100	0.0000*
	LGDPPC	0.2446	0.0994	2.4600	0.0190**
	LURB	−0.4551	0.3955	−1.1500	0.2570
	LPIQ	−0.0610	0.0199	−3.0700	0.0040*
SR	ΔLEGUSE	1.0869	0.1246	8.7300	0.0000*
	ΔLGDPPC	−0.0156	0.1252	−0.1200	0.9010
	ΔLURB	1.4711	1.6858	0.8700	0.3890
	ΔLPIQ	−0.0229	0.0155	−1.4800	0.1470
	_cons	6.1181	4.5906	1.3300	0.1910

NB: ADJ = speed of adjustment; LR = long-run and; SR = short-run.
* Rejection of the null hypothesis at 1% significance level.
** Rejection of the null hypothesis at 5% significance level.

Model 2 reveals a long-run relationship running from renewable energy consumption, fossil fuel energy consumption, nuclear energy generation, economic development and political institutional quality to environmental pollution; as the speed of adjustment [ECT(−1) = −0.78] is negative and statistically significant at 1%. The error correction term shows a 78% speed in correcting disequilibrium from the long-run equilibrium level of environmental pollution during the first-year to equilibrium after short-term shocks.

Evidence from Model 2 shows that a 1% increase in the renewable energy penetration decreases environmental pollution by 2865 kt in the long-run. It is important to note that a mere incorporation of renewable energy sources doesn't mean environmental sustainability if the generation and deployment of renewables are not done sustainably.

A 1% increase in fossil fuel energy penetration will propel environmental pollution by 10,436 kt in the long term, which is in line with (Sarkodie and Owusu, 2017a). According to their study, the overdependence on fossil fuel energy technologies thwarts efforts towards achieving a sustainable development. On the contrary, decoupling nuclear energy generation from fossil fuel yields no significant results in the long-term.

Per capita GDP (LGDPPC) is positive and significant at 1% whereas the sign of the squared per capita GDP ($LGDPPC^2$) is negative and statistically significant at 5%. The evidence shows that environmental pollution will increase by 14% in the long-run at the early stages of economic productivity but declines after achieving the required turning point in economic development. Accordingly, confirming the EKC hypothesis in the long-run revealed in Model 1.

In the same manner in Model 1, Model 2, the relationship between environmental pollution and political institutional quality is negative and insignificant.

The short-run equilibrium relationship in Model 2 reveals that the incorporation of renewable energy technologies in the energy portfolio will decline pollution by 2240 kt in the short-term. Thus, complementing the role of renewable energy in both long and short-term.

On the contrary, conventional sources of energy like coal, oil and natural gas will exacerbate environmental pollution by 8160 kt in the short-run. Accordingly, accentuating the aggravating impact of fossil fuels on atmospheric emissions.

The short-run equilibrium relationship in Model 2 further confirms the validity of the EKC hypothesis; this means pollution will accelerate by 6% parallelly with economic growth till it reaches the turning point of economic development then declines thereafter in the short term.

Even though nuclear energy is sustainable but nonrenewable, the short-run relationship between pollution and nuclear energy generation reveals that nuclear energy intensifies environmental pollution by 256 kt. Pollution from nuclear energy may be associated with the emission of radioactive substances and nuclear waste management (handling and disposal). It appears that the impact of nuclear energy on environmental pollution is lower compared to typical fossil fuel energy technologies like coal, oil, and gas (Owusu and Asumadu-Sarkodie, 2016). The short-run equilibrium relationship in Model 2 further reveals that the nexus between pollution and political institutional quality is negative and insignificant.

Business as usual in terms of renewable energy, fossil fuel, nuclear energy generation, economic growth and political institutional quality will decline environmental pollution by 37,415 kt in the short-term.

After examining the impact of disaggregated energy on environmental pollution, Model 3 presents the nexus between aggregate energy consumption, economic development, urbanization and political institutional quality. The estimation of Model 3 is based on a log-log regression presented in Table 6.

The results of Model 3 shows that the error correction [ECT(−1) = −0.73] is negative and statistically significant at 1%, hence, confirming a long-run relationship running from energy consumption, economic growth, urbanization and political institutional quality to environmental pollution. Model 3 shows a 73% speed of adjusting disequilibrium from the long-run level of environmental pollution to equilibrium during the first-year after short-term shocks.

The long-run equilibrium relationship in Model 3 shows that a 1% increase in aggregate energy consumption and economic development will intensify environmental pollution by 1.3% and 0.2%, confirming the work of Sarkodie and Owusu (2017c). They argued that aggregate energy consumption and economic growth work together, as such, exhibits a feedback effect. It appears that the parallel effect of energy consumption and economic development on environmental pollution is valid for developing countries. For energy efficiency to occur, it is expected that as economic growth increases, energy consumption should decline, but contrariwise in South Africa. On the contrary, while urbanization has no significant effect in both long- and short-run, political institutional quality declines environmental pollution by 0.1% in the long-run.

The short-run equilibrium relationship in Model 3 further confirms that aggregate energy consumption increases environmental pollution by 1.1% in the short-term, which is in line with (Sarkodie and Owusu, 2017b).

The study corroborates the validity of the EKC hypothesis using the Utest estimation by Lind and Mehlum (2010). The Utest estimation method is used to test for the presence of a U-shaped or inverted U-shaped relationship between a predictor variable and the response variable on an interval. The only condition of the Utest estimation is to have a level explanatory variable and a non-linear, quadratic or inverse term. Using the level of per capita GDP and the squared of per capita, the overall test shows the presence of an Inverted U-shape presented in Table 7. Thus, the results of the Utest confirms the validity of the EKC hypothesis in the disaggregate energy consumption model shown in Table 6. The Utest further reveals that the turning point of environmental pollution with respect to per capita income level occurs at ZAR 56,114 which corresponds to the year 2011 in the time series data.

In other to prevent spurious and bias inferences, the study employs diagnostic tests to examine the independence of the residuals in the three ARDL models. Table 8 reveals that the three ARDL models are free from 1st order autocorrelation (Durbin-Watson test), has no ARCH effects for higher order autocorrelation (ARCH LM test), has no serial correlation (Breusch Godfrey LM test), has a constant variance free from heteroskedasticity issues (Breusch-Pagan/Cook-Weisberg test), and has no omitted variables (Ramsey RESET test). Finally, the study examines the stability of the three ARDL models using the CUSUM and CUSUM Squared Plots depicted in Figs. 4–5. The cumulative sums (CUSUM) of the recursive residuals and CUSUM Squared Plots from the ARDL regression show that the plots are within the 95% confidence band graphs, hence, confirming the stability of the ARDL models.

Table 7
Verification and validation of EKC hypothesis.

	Lower bound	Upper bound	Extreme point
Interval	619	81,693	56,114
t-Value	8.7437	−3.1577	3.1600
p > t	0.0000	0.0014	0.0014

Table 8
Model verification and validation.

LM test	lags(p)	chi^2	df	Prob > chi^2
Model 1	1	0.0040	1	0.9491
Model 2	1	0.0000	1	0.9857
Model 3	1	3.1740	1	0.0748
Breusch-Godfrey LM test	**lags(p)**	**chi^2**	**df**	**Prob > chi^2**
Model 1	1	1.617	1	0.2036
Model 2	1	1.316	1	0.2513
Model 3	1	2.801	1	0.0942
Breusch-Pagan/Cook-Weisberg test				
Model 1	$chi^2(1)$	0.3500	Prob > chi^2	0.5559
Model 2	$chi^2(1)$	1.9100	Prob > chi^2	0.1673
Model 3	$chi^2(1)$	0.9400	Prob > chi^2	0.3318
Ramsey RESET test				
Model 1	F(3,32)	0.4500	Prob > F	0.7195
Model 2	F(3,30)	0.3600	Prob > F	0.7853
Model 3	F(3,33)	0.0500	Prob > F	0.9835
Durbin-Watson				
Model 1	d-Statistic(8,43)			2.2427
Model 2	d-Statistic(10,43)			2.2092
Model 3	d-Statistic(10,46)			2.1812

The study applies diagnostic tests to examine the independence of the residuals.

4.5. Discussion

The results of the empirical analysis from the nexus between disaggregate energy consumption and environmental pollution speak volumes on policy strategies that can help reduce environmental pollution without reducing access to energy as accentuated in the sustainable development goals.

Every large scale or commercial deployment of energy technologies always come with environmental trade-offs (IPCC, 2011). Yet, the long-term effect of renewable energy technologies improves environmental quality. The study revealed that the share of renewable energy declines environmental pollution while fossil fuel energy sources exacerbate pollution. Fossil fuel energy consumption takes center stage in South Africa's energy portfolio and is mainly dominated by coal and lignite. The 2017 Global Energy Statistics reveals that South Africa is the 6th in the world and 1st in Africa in terms of coal and lignite consumption and further ranks 2nd in terms of CO_2 intensity in the world (Enerdata, 2017).

However, substituting the finite and scare fossil fuel energy sources with renewable energy sources will not only ensure environmental quality but leads to energy-dependent economic emancipation. Since renewable energy sources are localized and cannot be traded internationally compared to fossil fuels, the utilization of the ubiquitous renewable energy sources reduces the dependency on fossil fuel importation thus, leading to energy security and economic productivity. Owusu and Asumadu-Sarkodie (2016) revealed that renewable energy has a direct relationship with sustainable development, due to its enormous opportunities which include energy access, social and economic development, reduction of environmental and health impacts.

Even though nuclear energy is a clean source of energy but unsustainable depending on the generation processes involved. The empirical study shows that nuclear energy promotes environmental pollution in South Africa in the short term. Perhaps, its associated pollution may be due to the technologies used to decommission and decontaminate past strategic nuclear facilities, and the improper nuclear waste disposal management practices.

Due to the small ratio of renewable energy penetration in the energy mix compared to fossil fuel energy sources, the aggregate energy

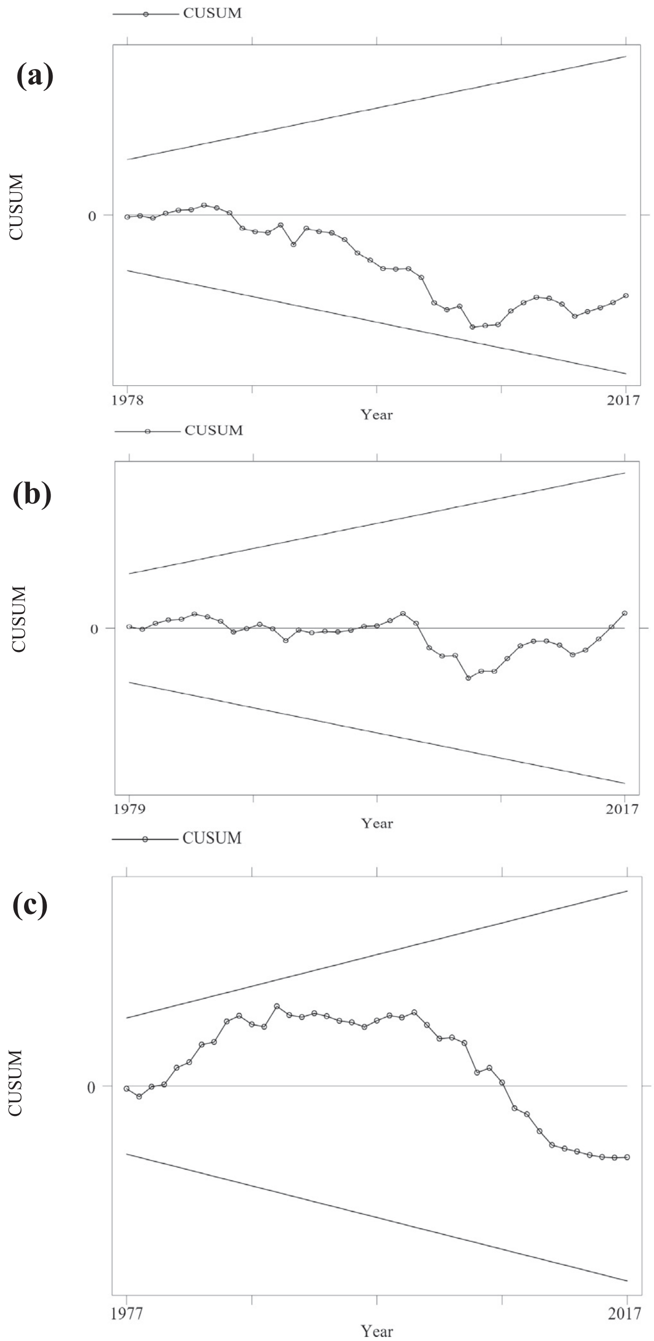


Fig. 4. (a) Model 1 (b) Model 2 and (c) Model 3: CUSUM plot for ARDL regression.

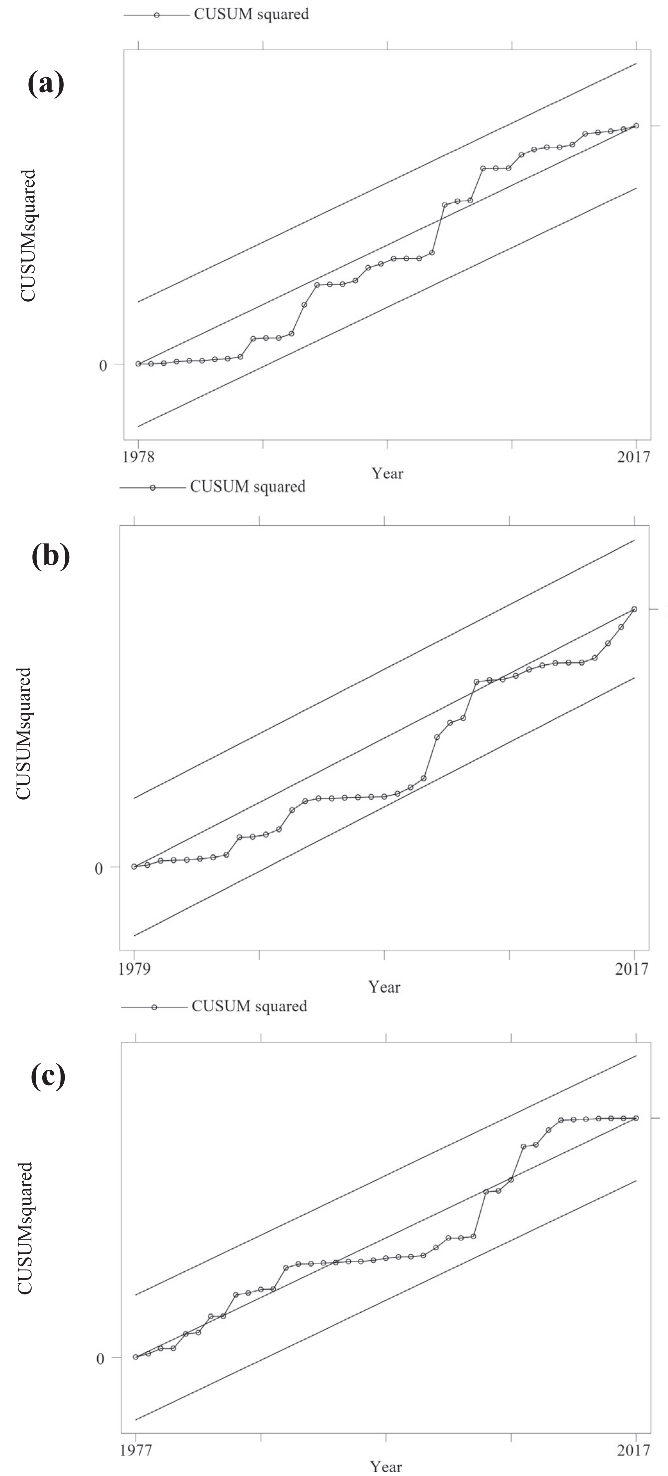


Fig. 5. (a) Model 1 (b) Model 2 and (c) Model 3: CUSUM squared plot for ARDL regression.

consumption accelerates environmental pollution. The IPCC reports show that energy consumption (heat and electricity) and its related services remain the highest contributor to greenhouse gas emissions.

Urbanization plays a weak or insignificant role in environmental pollution, perhaps due to enhanced economic activities in South Africa evidenced in the per capita GDP. However, urban concentrations are still one of the critical sensitivity indicators of vulnerability to climate change. Owusu et al. (2016); Asumadu-Sarkodie et al. (2015) revealed that an uncontrolled urban concentration in developing countries causes congestion and pressurizes available water resources, urban hydrology, and hydraulics leading to flooding and among others.

The study confirms the validity of the EKC hypothesis in South Africa, at a turning point of ZAR 56,114. The EKC hypothesis postulates that developing economies pollute more to grow their economy then clean later after attaining a specific turning point in economic development. It is therefore expected that environmental pollution will decline in South Africa at ZAR 56,114 while boosting economic productivity and decreasing energy intensity thus, an indication of energy efficiency.

Obviously, strong institutions and political leadership with the capacity to plan and manage policies and investments that support climate-smart development are an essential building block of low carbon, climate resilient societies (Foresight Africa (2017)). Political institutional quality plays a huge role in the social, governance and economic readiness to mitigate climate change and its impact. Hence, stringent social, governance and economic reforms and policies are

required by quality political institutions before adaptation options can be effected. As it stands, South Africa has a low climate change vulnerability with the readiness, however, adaptation options for climate change are still challenging.

5. Conclusion

To increase the global debate on climate change mitigation, the study examined the impact of disaggregate and aggregate energy, economic development, urbanization and political institutional quality on environmental pollution, from 1971 to 2017 with a case study in South Africa. South Africa remains Africa's economic giant, and the second most carbon-intensive country in the world due to their rich fossil fuel energy sources. However, their commitment to climate change mitigation and its impacts motivates its selection for the study. The EKC hypothesis is valid in South Africa and it was attained in 2011 at a turning point of ZAR 56,114. Evidence from the study shows that political institutional quality plays a huge role in the social, governance and economic readiness to mitigate climate change and its impact.

South Africa is a fossil-fuel-rich country in Africa, however, diversification of the energy portfolio by incorporating renewable energy sources will promote air quality and environmental sustainability while reducing their economy's vulnerability to price volatility. Based on the policy implications of the effect of disaggregate and aggregate energy consumption, economic growth, and political institutional quality on environmental pollution, the study proposes, first, a paradigm shift from energy and carbon-intensive industries to a service-oriented economy which will cause a structural economic change thus, aiding in the mitigation of climate change and its impacts. Second, there is a need for technological advancement in manufacturing industries and power sectors that employ advanced technologies such as carbon capture and storage, among others in other to promote energy efficiency. Finally, a structural economic change depends on the willingness by the Government to promote policies to decarbonize the economy and provide the conducive political environment that promotes clean and modernized energy, thus, promoting environmental quality. Renewable energy investment has a competitive disadvantage compared to fossil fuel and nuclear energy. For renewable energy technology to be attractive, it requires deployment policies that mutually include technological development (research and development, innovation and technological advancement), industry development (higher performance, affordable cost, and higher quality) and market development (available and accessible markets).

The study proposes a future research that examines the effect of research and development and renewable energy financing and policies on pollution reduction.

Acknowledgement

The usual disclaimer applies to the final version of this paper. SA Sarkodie is grateful to Macquarie University, Australia for the International Macquarie University Research Training Program (iMQRTP) Scholarship.

Declaration

There is no conflict of interest.

References

Adams, S., Klobodu, E.K.M., 2017. Urbanization, democracy, bureaucratic quality, and environmental degradation. J. Policy Model 39 (6), 1035–1051.
Adams, S., Adom, P.K., Klobodu, E.K.M., 2016a. Urbanization, regime type and durability, and environmental degradation in Ghana. Environ. Sci. Pollut. Res. 23 (23), 23825–23839.
Adams, S., Klobodu, E.K.M., Opoku, E.E.O., 2016b. Energy consumption, political regime and economic growth in sub-Saharan Africa. Energy Policy 96, 36–44.
Africa Progress Report, 2016. Finance and Banking.
Al-Mulali, U., Ozturk, I., Lean, H.H., 2015. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat. Hazards 79 (1), 621–644.
Al-Mulali, U., Solarin, S.A., Ozturk, I., 2016. Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. Nat. Hazards 80 (3), 1729–1747.
Apergis, N., Payne, J.E., Menyah, K., Wolde-Rufael, Y., 2010. On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecol. Econ. 69 (11), 2255–2260.
Asumadu-Sarkodie, S., Owusu, P.A., 2016. The relationship between carbon dioxide and agriculture in Ghana: A comparison of VECM and ARDL model. Environ. Sci. Pollut. Res. 23 (11), 10968–10982.
Asumadu-Sarkodie, S., Owusu, P.A., Rufangura, P., 2015. Impact analysis of flood in Accra, Ghana. Adv. Appl. Sci. Res. 6 (9), 53–78.
Baker, L., 2017. Commercial-scale renewable energy in South Africa and its progress to date. IDS Bull. 48 (5–6).
Bhattacharya, M., Churchill, S.A., Paramati, S.R., 2017. The dynamic impact of renewable energy and institutions on economic output and CO2 emissions across regions. Renew. Energy 111, 157–167.
Bilgili, F., Koçak, E., Bulut, Ü., 2016. The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. Renew. Sust. Energ. Rev. 54, 838–845.
Brown, R.L., Durbin, J., Evans, J.M., 1975. Techniques for testing the constancy of regression relationships over time. J. R. Stat. Soc. Ser. B Methodol. 149–192.
Chiu, C.L., Chang, T.H., 2009. What proportion of renewable energy supplies is needed to initially mitigate CO2 emissions in OECD member countries? Renew. Sust. Energ. Rev. 13 (6–7), 1669–1674.
Dogan, E., Seker, F., 2016a. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew. Sust. Energ. Rev. 60, 1074–1085.
Dogan, E., Seker, F., 2016b. Determinants of CO2 emissions in the European Union: the role of renewable and non-renewable energy. Renew. Energy 94, 429–439.
Eberhard, A., Kåberger, T., 2016. Renewable energy auctions in South Africa outshine feed-in tariffs. Energy Sci. Eng 4 (3), 190–193.
EIA, 2017. Nuclear electricity net generation. Retrieved from. http://knoema.com/EIAINTL2018/international-energy-data-monthly-update.
Enerdata, 2017. Global energy statistical yearbook 2017. Retrieved from. https://yearbook.enerdata.net.
Farhani, S., Shahbaz, M., 2014. What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO2emissions in MENA region? Renew. Sust. Energ. Rev. 40, 80.
Foresight Africa, 2017. Top Priorities for the Continent in 2016. Brookings Institute, Washington DC.
Forsberg, C.W., 2009. Sustainability by combining nuclear, fossil, and renewable energy sources. Prog. Nucl. Energy 51 (1), 192–200.
Franco, S., Mandla, V.R., Rao, K.R.M., 2017. Urbanization, energy consumption and emissions in the Indian context. A review. Renew. Sust. Energ. Rev. 71, 898–907.
Heal, G., 2009. Reflections—the economics of renewable energy in the United States. Rev. Environ. Econ. Policy 4 (1), 139–154.
IPCC, 2011. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., Matschoss, P. (Eds.), Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
Irfan, M., Shaw, K., 2017. Modeling the effects of energy consumption and urbanization on environmental pollution in South Asian countries: a nonparametric panel approach. Qual. Quant. 51 (1), 65–78.
Jebli, M.B., Youssef, S.B., Ozturk, I., 2016. Testing environmental Kuznets curve hypothesis: the role of renewable and non-renewable energy consumption and trade in OECD countries. Ecol. Indic. 60, 824–831.
Kripfganz, S., Schneider, D.C., 2018. Response Surface Regressions for Critical Value Bounds and Approximate p-Values in Equilibrium Correction Models.
Lenzen, M., 2008. Life cycle energy and greenhouse gas emissions of nuclear energy: a review. Energy Convers. Manag. 49 (8), 2178–2199.
Liddle, B., 2014. Impact of population, age structure, and urbanization on carbon emissions/energy consumption: evidence from macro-level, cross-country analyses. Popul. Environ. 35 (3), 286–304.
Lind, J.T., Mehlum, H., 2010. With or without U? The appropriate test for a U-shaped relationship. Oxf. Bull. Econ. Stat. 72 (1), 109–118.
Martínez-Zarzoso, I., Maruotti, A., 2011. The impact of urbanization on CO2 emissions: evidence from developing countries. Ecol. Econ. 70 (7), 1344–1353.
Menyah, K., Wolde-Rufael, Y., 2010. CO2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy 38 (6), 2911–2915.
Mert, M., Bölük, G., 2016. Do foreign direct investment and renewable energy consumption affect the CO 2 emissions? New evidence from a panel ARDL approach to Kyoto Annex countries. Environ. Sci. Pollut. Res. 23 (21), 21669–21681.
Mohiuddin, O., Sarkodie, S.A., Obaidullah, M., 2016. The relationship between carbon dioxide emissions, energy consumption, and GDP: a recent evidence from Pakistan. Cogent Eng. 3 (1), 1210491. https://doi.org/10.1080/23311916.2016.1210491.
Nakumuryango, A., Inglesi-Lotz, R., 2016. South Africa's performance on renewable energy and its relative position against the OECD countries and the rest of Africa. Renew. Sust. Energ. Rev. 56, 999–1007.
Owusu, P., Asumadu-Sarkodie, S., 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng. 3 (1), 1167990. https://doi.org/10.1080/23311916.2016.1167990.

Owusu, P.A., Asumadu-Sarkodie, S., Ameyo, P., 2016. A review of Ghana's water resource management and the future prospect. Cogent Eng. 3 (1), 1164275. https://doi.org/10.1080/23311916.2016.1164275.

Paramati, S.R., Sinha, A., Dogan, E., 2017. The significance of renewable energy use for economic output and environmental protection: evidence from the Next 11 developing economies. Environ. Sci. Pollut. Res. 1–15.

Pesaran, M.H., Shin, Y., 1998. An autoregressive distributed-lag modelling approach to cointegration analysis. Econ. Soc. Monogr. 31, 371–413.

Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. J. Appl. Econ. 16 (3), 289–326.

Phillips, P.C., Perron, P., 1988. Testing for a unit root in time series regression. Biometrika 75 (2), 335–346.

Ploberger, W., Krämer, W., 1992. The CUSUM test with OLS residuals. Econometrica 271–285.

Saidi, K., Mbarek, M.B., 2016. Nuclear energy, renewable energy, CO2 emissions, and economic growth for nine developed countries: evidence from panel Granger causality tests. Prog. Nucl. Energy 88, 364–374.

Sarkodie, S.A., Owusu, P.A., 2017a. The causal effect of carbon dioxide emissions, electricity consumption, economic growth and industrialization in Sierra Leone. Energy Sources Part B Econ. Plan. Policy 12 (01):32–39. https://doi.org/10.1080/15567249.2016.1225135.

Sarkodie, S.A., Owusu, P.A., 2017b. The causal nexus between energy use, carbon dioxide emissions and macroeconomic variables in Ghana. Energy Sources Part B Econ. Plan. Policy 12 (06):533–546. https://doi.org/10.1080/15567249.2016.1225134.

Sarkodie, S., Owusu, P., 2017c. A multivariate analysis of carbon dioxide emissions, electricity consumption, economic growth, financial development, industrialization and urbanization in Senegal. Energy Sources Part B Econ. Plan. Policy 12 (01):77–84. https://doi.org/10.1080/15567249.2016.1227886.

Sarkodie, S.A., Strezov, V., 2018. Assessment of contribution of Australia's energy production to CO2 emissions and environmental degradation using statistical dynamic approach. Sci. Total Environ. 639:888–899. https://doi.org/10.1016/j.scitotenv.2018.05.204.

Shafiei, S., Salim, R.A., 2014. Non-renewable and renewable energy consumption and CO 2 emissions in OECD countries: a comparative analysis. Energy Policy 66, 547–556.

UoG, 2017. Political institutional quality (relative factor scores). Retrieved from. http://knoema.com/QOGISD2018/quality-of-government-institute-standard-dataset-version-january-2018.

Walwyn, D.R., Brent, A.C., 2015. Renewable energy gathers steam in South Africa. Renew. Sust. Energ. Rev. 41, 390–401.

Weideman, J., Inglesi-Lotz, R., Van Heerden, J., 2017. Structural breaks in renewable energy in South Africa: a Bai and Perron break test application. Renew. Sust. Energ. Rev. 78, 945–954.

World Bank, 2016. World development indicators. Retrieved from. http://data.worldbank.org/country.

World Economic Outlook (2016).

World Nuclear Association, 2017. Nuclear Power in South Africa.

Zoundi, Z., 2017. CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. Renew. Sust. Energ. Rev. 72, 1067–1075.